EFFECT OF PULSE FREQUENCY AND DURATION IN GUIDING SALMON FINGERLINGS BY ELECTRICITY

RESEARCH REPORT 43

FISH AND WILDLIFE SERVICE

UNITED STATES DEPARTMENT OF THE INTERIOR

ABSTRACT

The relation of pulse frequency and pulse duration to the effectiveness of a moving field of pulsating direct current in directing salmon fingerlings was explored under controlled laboratory conditions, utilizing a single-row electrode array.

The experiments indicated that, within the range of conditions examined, pulse frequencies of 3 to 4 pulses per second and pulse durations of 15 to 30 milliseconds were most effective in diverting fingerlings; and that the effectiveness of the electrical array was related to the duty cycle. Those conditions most nearly approaching a duty cycle of 0.10 were most effective. No mortality occurred at any of the pulse frequencies and pulse durations tested below a duty cycle of 0.10.

EFFECT OF PULSE FREQUENCY AND DURATION IN GUIDING SALMON FINGERLINGS BY ELECTRICITY

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RESEARCH REPORT 43

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United States Department of the Interior, Fred A. Seaton, *Secretary*

UNITED STATES GOVERNMENT PRINTING OFFICE • WASHINGTON • 1956

For sale by the Superintendent of Documents, United States Government Printing Office
Washington 25, D. C. - Price 15 cents

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EFFECT OF PULSE FREQUENCY AND DURATION IN GUIDING SALMON FINGERLINGS BY ELECTRICITY

One of our most important sources f protein food, the Pacific salmon, endangered by the construction of umerous dams on the Columbia iver and other rivers in the Pacific Jorthwest. These dams, although sually equipped with fish ladders iat are successful in passing the dult salmon to their spawning rounds, still constitute a major azard to seaward-bound fingerlings. Iigrants moving downstream have reat difficulty in finding safe pas- ge past such obstacles because the shways carry such a small volume f water in comparison to that going ver a dam or through the power nits. For dams such as those on ie Baker River in Washington, ith a spillway height of 250 feet, ie mortality of young sockeye and ho going over the spillway is some- mes as high as 60 to 70 percent Hamilton and Andrew, 1954). Re- nt studies (Schoeneman and Junge, 954) on the Elwha River in Wash- gton indicated the following losses young fish: Glines Dam, with a illway height of 200 feet, showed a inook and silver fingerling mortal- y of approximately 30 percent rough the turbines; and Elwha am, height 100 feet, showed a ortality of 37 percent over the illway.

For the past 3 years biologists at the Seattle, Wash., laboratory of the United States Fish and Wildlife Service have been investigating methods of guiding fingerlings away from dangerous areas at dams by means of electricity. The studies have included experiments on the orientative reactions of fish to various voltages, pulse frequencies, pulse durations, wave forms, and current densities.[1] The studies also explored the relation of these electrical properties to fish mortality (Collins, Volz, and Trefethen, 1954). Other experiments, part of an intermediate phase between basic studies and full-scale field experiments, inquired into the effectiveness of a narrow d. c. electrical barrier using two rows of electrodes to divert salmon fingerlings (Trefethen 1955), and the effectiveness of a wider bizonal electrical field.

The experiments with a bizonal field were made in an attempt to reduce the danger of injury to larger fish entering the field, without lessening the effectiveness of the device in directing small fish. Three rows of electrodes were used, the downstream row electrically negative and the middle and upstream rows elec-

[1] Collins, Gerald B., C. D. Volz, and R. H. Lander. The effectiveness of pulsating direct current in controlling movements of salmon fingerlings. United States Department of the Interior, Fish and Wildlife Service, Washington, D. C. (Unpublished MS.)

trically positive. The distance between the downstream and middle rows was half that between the middle and upstream rows. The voltages in the field were regulated by means of a series parallel resistance divider, in such fashion that the downstream field had a voltage gradient twice that of the upstream field (fig. 1).

The results obtained in experiments with the bizonal array was

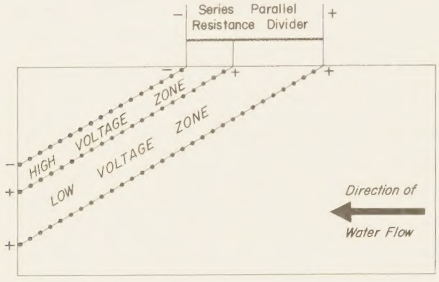

Figure 1.—Diagram of a 3-row bizonal voltage field

equally effective in diverting large and small fish. This type of electrode arrangement was tried in the field at Jenkins Creek in the spring of 1954.[2] The large number of electrodes required at Jenkins Creek made it apparent, however, that for large-scale field operations a simpler array with fewer electrodes and a lower power requirement was needed.

The experiments with which this paper is concerned utilize a type of electrical barrier designed to overcome the objectionable features of the bizonal array. The new array, having only one row of widely spaced electrodes, was developed in the Seattle laboratory and tested there during August and September 1954. As a result of those tests, the findings of which are reported here, enough data were accumulated to use the information in field studies in the Icicle River at Leavenworth, Wash., in the fall of 1954.

Acknowledgment is due Charles Ellis, supervisor of hatcheries, State of Washington, and personnel at the Issaquah State Hatchery for their assistance in procuring the fish; Charles D. Volz, who designed the electronic equipment; and Reed E. Duncan, Galen H. Maxfield, and Parker S. Trefethen, for their critical review of the manuscript and many valuable suggestions.

[2] Mason, J. E., S. Murai, and H. L. Garrett. Preliminary summary of electrical fish-guiding operations at Jenkins Creek near Covington, Wash., in 1954. United States Department of the Interior, Fish and Wildlife Service, Washington, D. C. (Unpublished MS.)

ELECTRICAL APPARATUS

The electrode array used in these experiments differs from arrays used previously in that it consists of a single row of electrodes. Instead of an electrical field created between two rows of electrodes, electrical fields are created successively between adjacent electrodes. The electrical pulse is switched sequentially to the electrodes in the following manner: No. 1 electrode is made negative and No. 2 electrode positive; the unit then switches in such a manner that No. 2 electrode becomes negative and No. 3 electrode positive; the unit switches again so that No. 3 electrode becomes negative and No. 4 electrode positive; the unit switches a third time making No.

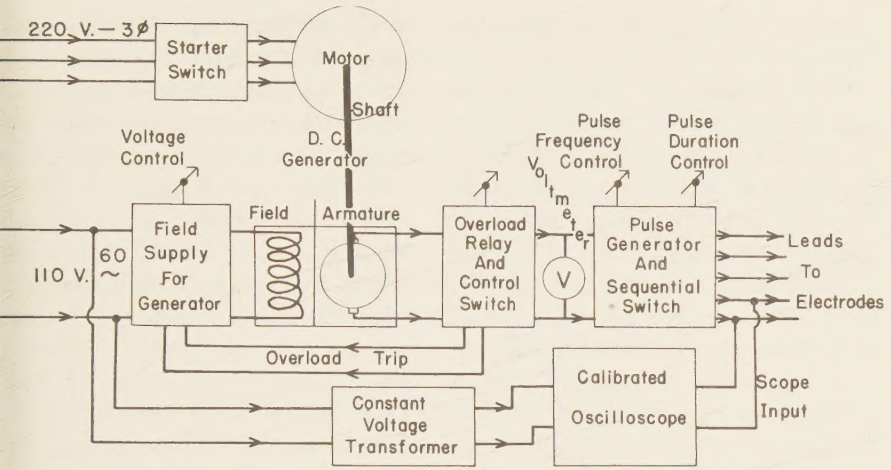

Figure 2.—Block diagram of electrical equipment.

electrode negative, and No. 5 lectrode positive. The pulse then eturns to the initial pair of elec-rodes and the cycle is repeated.

A schematic description of the witching unit designed to perform his operation is shown in block iagram (fig. 2). A detailed de-cription of the electrical circuits ontrolling the square-wave pulses sed throughout this experiment nd determining the sequence of ring will be published later.

The direct current was provided by a 10-kilowatt motor-generator set, with a maximum output of 500 volts at 20 amperes. A calibrated oscilloscope, operated from a volt-age-regulating transformer, was used for setting voltage and observing wave form, and another special os-cilloscope was used for plotting the field with a voltage gradient probe. As a safety device, an overload relay with push-button reset was installed to prevent serious damage to the electrical apparatus.

FACILITIES

The new sequentially pulsed, sin-le-row array was tested in an ex-erimental tank (fig. 3), 24 feet by) feet, made of concrete blocks set n a cement floor and covered with nsulating paint to minimize distor-on of the electrical field. It was lled with water to a depth of 10 ches and a stream-flow condition as simulated by means of a re-rculating pump to move the water rough the experimental area at an

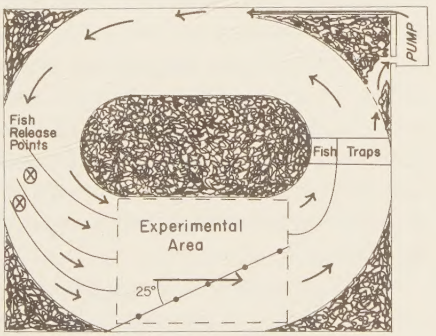

Figure 3.—Experimental tank showing points of release and traps.

average velocity of 0.5 foot per second.

The experimental area (fig. 3) was approximately 10 feet wide and 15 feet long. Four curved plywood vanes were installed upstream for straightening the flow of water through the experimental area. Downstream, the area was divided by a plywood vane into narrow and wide channels, 3 and 7 feet wide at their respective entrances. By installing traps (fig. 4) in each of these channels, the number of fish entering each channel could be counted.

Figure 4.—Trapping arrangement, showing procedure used in counting fish.

The lower, or downstream, ends of the traps consisted of fixed barriers, constructed of wooden frames over which ½-inch hardware cloth was stapled and held in place by "C" clamps for easy removal when the tank was drained and cleaned. The upper ends of the traps were closed off by means of removable nylon-net screens, which were placed in position at the end of each test. Crowders were made to confine the fish to a small area for easy collecting and counting.

The electrode array consisted of a single row of 2-inch tubular aluminum electrodes, spaced 30 inches apart. The array was suspended across the experimental area at an angle of 25° from the direction of water flow. The downstream end of the array was placed immediately in front of the plywood vane separating the 3- and 7-foot channels (fig. 3). With such an arrangement, any fish moving through the experimental area had to pass through the electrode array to reach the larger channel. Grounding screens of highly conductive zinc-copper wire mesh, 30 inches long and 12 inches high, were placed at each end of the array to limit the electrical field and to prevent fish from escaping around the ends of the electrical field. A constant voltage of 210 volts was applied across each pair of electrodes with the resultant electric field shown in figure 5.

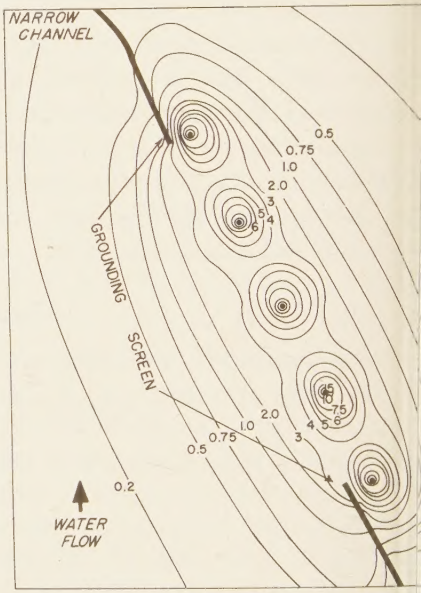

Figure 5.—Diagram of voltage contours measured by a voltage-gradient pro The numbers represent maximum volt readings in volts per inch in the horizo plane taken 1 inch from the bottom the tank.

Troughs were constructed inside ıe laboratory surrounding the ex-erimental area to hold fish prior) testing. They were 6 feet long ıd 9 inches wide, with 1-foot)acers dividing each trough into x equal compartments.

The test fish were silver salmon ngerlings (*O. kisutch*) ranging in ngth from 7 to 11 centimeters. hey were brought in from the Washington State hatchery at Issaquah in an aerated tank truck in lots of 3,000 to 5,000 fish. On arrival they were placed in two 6-foot circular metal holding tanks.

Four 500-watt lamps attached to a variable autotransformer controlled the light intensity within a range from less than 1 foot-candle to 3.4 foot-candles.

EXPERIMENTAL PROCEDURES

The experimental method was to xpose the fish in systematic fashion) an electrical guiding array and) measure the guiding effective-ess of various combinations of ulse frequency and pulse duration y the relative numbers of fish ecovered in each trap at the end f a 5-minute test period. To)tain a reliable comparison of the uiding effectiveness of various ulse frequencies and pulse dura-ons, equal numbers of fish with milar environmental backgrounds ere used to test each condition.

Fish to be tested in the morning ere placed in the troughs during ıe previous evening and held vernight; fish to be tested in the ternoon were placed in the troughs the start of the working day; and sh to be tested in the evening were aced in the troughs at noon. y this method, each fish had a eriod of some 6 to 12 hours in ıe trough before being subjected a test, thus reducing the fright action caused by handling.

Preliminary tests indicated that ıe reactions of different groups of perimental fish might vary during ıe course of the day, due possibly changes in light intensity and water temperatures in the tanks. Variability of results due to these conditioning influences was minimized by the following experimental design. Each morning one control "power off" was run followed by six different tests in which the conditions were varied by changes in the pulse frequency and/or pulse duration. Tests were repeated in this order under still different conditions in the afternoon and again in the evening. Since 28 combinations of pulse frequency and pulse duration were tested, it required about 1½ days to finish a series. The pulse frequencies and pulse durations tested in the afternoon of the first day were repeated on the morning of the second day; those tested the first morning were tested again in the evening of the second day; and those tested in the evening of the first day were repeated on the afternoon of the second day, et cetera, until two replicates had been run in the morning, two in the afternoon and two in the evening, for each test condition.

To minimize any chance of a learning response, fish were never used more than twice. The tests were so regulated that each test

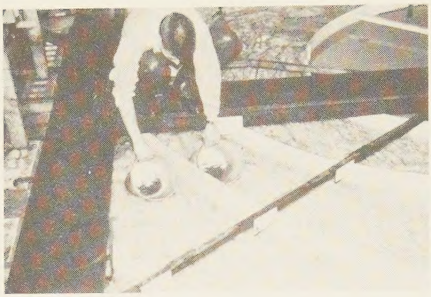

Figure 6.—Test fish being released in the two middle channels above the experimental area.

condition had a similar distribution of fish that had never been exposed to the electrical array and of fish that had been exposed only once.

The experimental tank was drained and filled with fresh water once a week to maintain the desired levels of water resistance (14,000–16,000 ohms/cm.[3]) and water temperature (12° to 14° C.)

At the beginning of each experiment, the switching unit was turned on and the electrodes energized. A visual check on whether the electrode array was pulsing properly was accomplished by a "strobe" light attached across one pair of electrodes and concealed from the fish to prevent a possible light response. Twenty-five fingerlings were released in each of the two middle channels (fig. 6) above the array of electrodes and allowed to move downstream (fig. 7) into the two traps at the lower end. To expedite the movement of fish downstream, the experimental area was darkened for the 5-minute duration of each test. At the end of this period the lights were turned up very slowly by the use of a variable autotransformer, and the traps were closed. The fish in each trap were then crowded into a sma area and counted. Those remai ing above the traps were cleared o of the experimental area before t next test.

As all of the fish released did n go into the traps at the end of t 5-minute test period, a sample 50 fish for each test was found be necessary to yield a sufficie number of fish in the trap. If least 30 fish entered the trap, t number recovered was considere sufficient for statistical treatmen if less than 30, the test was di carded and was repeated.

The voltage gradients in t electrical field were measured by voltage-gradient probe. Pulse fr

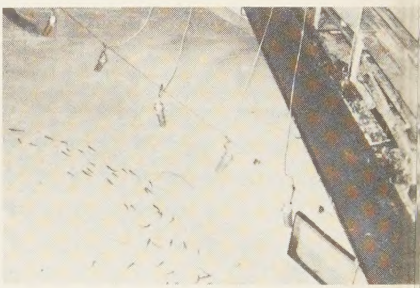

Figure 7.—Salmon fingerlings being divert by the electrical field.

quency was calibrated by a lo frequency oscillator, and pulse du tion was measured by a standa calibrated oscilloscope.

Water resistance was measur with an industrial conductiv bridge and the water temperat with a standard mercury th mometer. These measureme were taken once a day through the test period.

Water velocities were measu by an impeller-type current me The fish size of 7 to 11 centimet

rom tip of snout to tip of tail) as determined from a random mple of fish brought in from the tchery.

The salmon fingerlings were ex- sed to 28 different combinations pulse frequencies and pulse dura- ons, ranging in frequency from 1 6 pulses per second, and in pulse ration from 5 to 60 milliseconds. ree hundred fish were released der each of the conditions tested, a total of 8,400 fish. The range recoveries was from 213 to 262 h (71–87 percent). The mean covery was 238 fish. The data corded in detail in the appendix . 13) are summarized in table 1. ne percentage of fish recovered in the narrow channel was the basis for comparison of the guiding effectiveness of the pulse frequencies and pulse durations tested.

Chi-square tests of significance were run to determine whether the results were uniform within each of the conditions tested, "power-off" control and "power on" test condition. All chi-square values were below the 95-percent chi-square significance level. Table 1 shows chi-square values for uniformity tests of control and test conditions.

After determining that the percentages of fish recovered in the narrow channel were consistent within each test condition, a means of breaking down the 28 different

ble 1.—Summary of fish recoveries for control and for all conditions tested, with chi-square values of homogeneity

[Control—22 replicates; test runs—6 replicates each]

Test conditions		Number of fish recovered	Recovered in narrow channel		Chi-square [1]
Pulse frequency (pulses/sec.)	Pulse duration (millisec.)		Number	Percent	
	20	244	173	70.9	3.84
	30	228	161	70.6	.91
	40	227	168	74	.26
	60	236	167	70.8	1.19
	10	239	165	69	3.10
	20	213	163	76.5	.22
	30	220	166	75.5	.83
	40	217	156	71.9	4.85
	60	229	157	68.6	2.33
	5	262	189	72.1	1.79
	10	230	175	76.1	1.67
	20	234	188	80.3	1.33
	30	261	214	82	6.06
	40	240	190	79.2	3.58
	60	256	207	80.9	10.32
	5	252	180	71.4	2.60
	15	240	197	82.1	3.33
	25	245	195	79.6	4.81
	35	254	192	75.6	1.61
	45	252	175	69.4	2.45
	5	240	186	77.5	5.29
	10	230	181	78.7	2.24
	20	232	188	81	2.60
	30	231	189	81.8	5.37
	40	257	168	65.4	4.30
	5	242	159	65.7	.67
	10	236	170	72	1.24
	20	234	171	73.1	1.73
trol		1,018	262	25.7	4.26

[1] For P=.05 the value of chi square is 11.07 for all entries except control, for which it is 32.67.

tests into a few optimum combinations of pulse frequencies and pulse durations was made possible by chi-square tests of significance between them.

The effect of various pulse frequencies and pulse durations on the percentage of fish recovered in the narrow channel is shown graphically in figure 8. Preliminary tests indicated that combinations of pulse frequency and pulse duration, both below and above certain duty cycles,[3] resulted in lowered effectiveness of the guiding array. At duty cycles below 0.015, the effectiveness of the array is reduced considerably; and above a 0.18 to 0.20 duty cycle, mortality increases and effectiveness of the array decreases. Furthermore, one of the purposes of this experiment was t find combinations of pulse fr quency and pulse duration that a effective in diverting salmon finge lings at low duty cycles whic require less power. Therefore, tho test conditions falling outside th duty-cycle range indicated were n tested in this experiment.

[3] Duty cycle is defined as pulse frequency × pulse duration.

PULSE DURATION

Analysis of the data indicate that at any given frequency, the was no appreciable change in th percentage of fish recovered in th narrow channel as the duration the pulse was increased. Table shows chi-square values of duration tested within each frequency.

There was no significant diffe ence in the number of fish recovere in the narrow channel at frequencie of 1, 2, and 6 pulses per second, bu

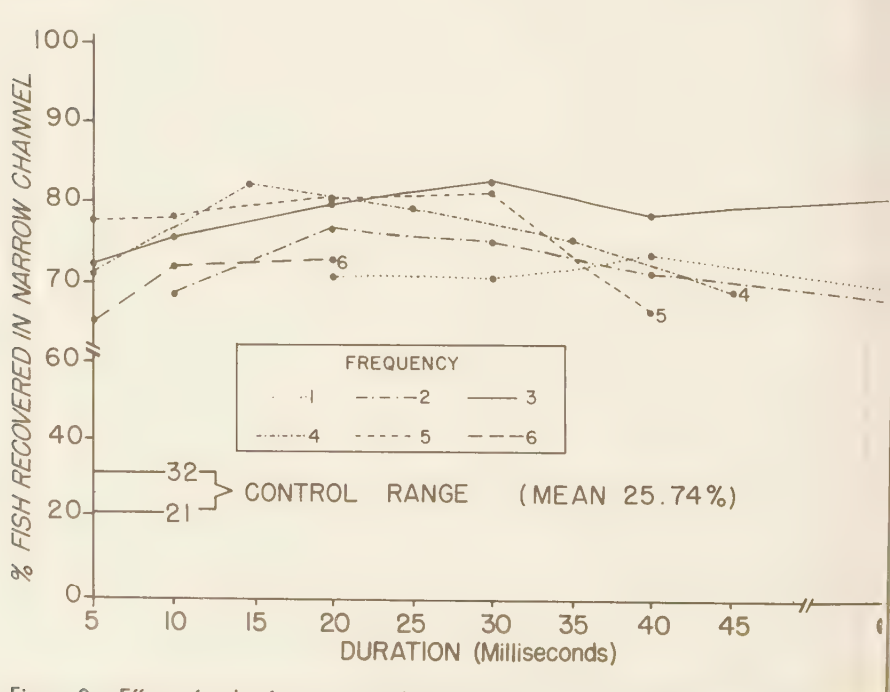

Figure 8.—Effect of pulse frequency and pulse duration on the percentage of fish recove in the narrow channel.

Table 2.—Effect of various pulse durations at constant pulse frequencies on recovery of salmon fingerlings

Pulse frequency	Number of replicates	Number of fish recovered	Recovered in narrow channel		x^2	x^2 value at $P=.05$
			Number	Percent		
	4	935	669	71.6	0.80	7.81
	5	1,118	807	72.2	5.45	9.49
	6	1,483	1,163	78.4	[1] 12.00	11.07
	5	1,243	939	75.5	[1] 16.92	9.49
	5	1,190	912	76.6	[1] 26.59	9.49
	3	712	500	70.2	4.10	5.99

[1] Significant.

ignificant differences did occur at requencies of 3, 4, and 5 pulses er second. Upon reexamination f the data, certain combinations f frequency and duration tested ere both below and above the 0.02 0.18 duty-cycle range that had een found to be most effective in reliminary experiments. When ese were excluded from the data nd another chi-square analysis was n, no significant difference was oted in the effectiveness of the elec-ode array when the pulse duration as varied at any of the six frequen-es tested. The following test con-itions (table 3) were excluded:

Table 3.—Test conditions excluded

Fre-quency (pulse/ second)	Dura-tion (milli-sec.)	Duty cycle	Num-ber of fish recov-ered	Recovered in narrow channel	
				Num-ber	Per-cent
	20	0.02	244	173	70.9
	10	.02	239	165	69.0
	5	.015	252	180	71.4
	60	.18	256	207	[1] 80.9
	5	.02	252	175	69.4
	45	.18	262	189	72.1
	40	.20	257	168	65.4
ll fre-quen-cies			1,506	1,050	69.7

[1] Not included in chi-square analysis.

With the exception of a pulse fre-ency of 3 pulses per second and a lse duration of 60 milliseconds, the excluded test conditions had the same relative effectiveness in diverting the fingerlings (the chi-square value for table 3 is 3.71; the value at $P=.05$ is 11.07).

PULSE FREQUENCY

Chi-square significance tests were run to determine if significant differences existed among the six frequencies tested within a duty-cycle range of 0.02 to 0.18. Table 4 gives the chi-square values obtained for (a) the six frequencies; (b) frequencies of 1, 2, and 6 pulses per second; (c) frequencies of 3, 4, and 5 pulses per second; and (d) the means of the frequencies of 1, 2, 6 and of 3, 4, 5 pulses per second.

Table 4.—Chi-square values for tests between pulse frequencies

Frequency (pulse/ second)	Number of fish recovered	Recovered in narrow channel		x^2	x^2 value at $P=.05$
		Number	Percent		
(a) 1 to 6	4,919	3,733	75.9	[1] 41.6	11.07
(b) 1, 2, 6	2,282	1,638	71.8	.2	5.99
(c) 3, 4, 5	2,637	2,095	79.4	.0	5.99
(d) Mean of 1, 2, 6 and 3, 4, 5	4,919	3,733	75.9	[1] 4.1	3.84

[1] Significant.

When only those conditions falling within a duty-cycle range of 0.02

to 0.18 were utilized, the breakdown of percentage of fish recovered in the narrow channel was such that two levels of effectiveness in diverting salmon fingerlings existed. These were pulse frequencies of 3, 4, and 5 pulses per second with a mean of 79.4 percent of the fish recovered in the narrow channel, and pulse frequencies of 1, 2, and 6 pulses per second with a mean of 71.8 percent recovered. Results from the chi-square analysis of differences between frequencies showed that frequencies of 3, 4, and 5 pulses per second were the most effective in directing salmon fingerlings, within the range of conditions tested in this series of experiments.

MORTALITY RELATIONSHIPS

Further examination of the results shows some loss of fish above certain pulse frequencies and pulse durations (appendix tables A to G, pp. 13–19) and no mortality under control conditions — indicating a mortality threshold in the electrical conditions tested. "Mortality was interpreted to include any fish that had not recovered equilibrium within 1 hour after exposure to the electrical field" (Collins, Volz, and Trefethen, 1954). The maximum mortality that took place was less than 5 percent, while average mortality was less than 3 percent. To be certain that electricity was the cause of loss, daily mortality records of the fish in the holding tanks were examined. There appeared to be no difference in the mortality rates of unexposed and exposed fish during the 2 months that the fish were held after the tests. Inspection of the data indicated that mortalities did not increase appreciably in fi exposed a second time, and wh the results were grouped, as sho in table 5, it was apparent that appreciable increase in mortali occurred.

Table 5.—Effect on mortality rates of o and two exposures to array

Number of exposures	Date	Number of fish used	Deaths	
			Number of fish	Pe ce
1	Nov. 15–19, 1954	4,950	34	
2	Nov. 22–26, 1954	3,450	31	

The relation of duty cycle mortality and percentage of fi guided is indicated in figure 9. N mortality occurred in any of t tests in which a duty cycle of le than 0.10 was used, while mortali did occur in all tests with du cycles greater than 0.10. Regre sion equations were computed duty cycle in relation to the pe centage of fish recovered in t narrow channel, to determine op mum pulse frequencies and du tions.

Equation I represents those co ditions resulting in no mortality a equation II those associated wi mortality. Tests were run with t hypothesis that the slopes of t equations, b, were equal to 0, that no relation existed between (duty cycle) and Y (percentage fish recovered in the narrow cha nel). Equation I ($Y=1.09X$ 0.695) differed significantly fro equal to 0; $t=2.31$, greater than 5-percent significance level fo with 17 degrees of freedom, ± 2.11. That is, the percentag fish recovered in the narrow cha

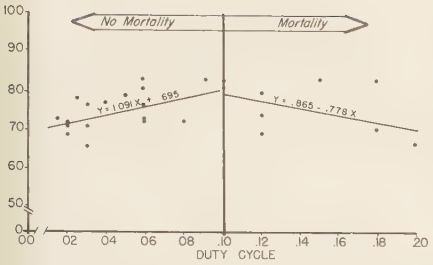

Figure 9.—Relation of duty cycle to the percentage of fish recovered in the narrow channel.

ncreased as the duty cycle in-reased, to the point where mortal-ty started, according to the regres-ion equation computed. Equation II ($Y=0.865-0.778X$) did not differ significantly from b equal to 0; $t=-1.2$, $< t=\pm 2.36$, the 5-percent significance level with 7 degrees of freedom, although a slight inverse slope existed.

This analysis shows that under the conditions tested, the most effective duty cycle for diverting fish is between 0.06 and just under 0.10, in the middle frequency range (i. e., pulse frequency 3, pulse duration 20 and 30 milliseconds; pulse frequency 4, pulse duration 15 and 25 milliseconds).

APPLICABILITY OF FINDINGS

In the development of an elec-rical array for practical use in uiding salmon fingerlings, there re several factors to consider.)ne such factor is the power re-uirement. Even at dams where he cost of electricity is relatively nexpensive, an array requiring an xcessive power load would be mpractical. In addition to cost f the electricity, the cost of main-aining electronic equipment, which ncreases greatly with heavy power oads, must be considered. Another mportant factor is the amount of pparatus that must be maintained n the water. On a large stream uch as the Columbia River, float-ng debris, fluctuating water levels nd velocities, and navigation, make nstallation and maintenance of pparatus in the water difficult. f the number of electrodes could e reduced the problem of holding he electrical apparatus in place ould be diminished, installation nd maintenance costs would be essened considerably, and inter-ference with water flow would be decreased.

From a practical standpoint, the sequentially pulsed, single-row array appears to be one of the most promising of the guiding arrays we have tested to date. It requires relatively few electrodes and the fish are diverted successfully with very little power. In the laboratory tests, a duty-cycle range from 0.06 to 0.10 was found to be effective in diverting the salmon fingerlings. This means that the electrodes were energized only 6 to 10 percent of the time. With this low power requirement, guiding arrays thousands of feet in length would be feasible. Indications are that the single-row array will be effective with all sizes of fingerlings, accomplishing the same purpose for which the bizonal array was intended, with perhaps even higher guiding efficiency.

The experiments examining the relation of pulse frequency and pulse duration to guiding effective-

ness are the first of a series of such experiments now being conducted with the sequentially pulsed, single-row electrode array. The influence of other factors such as voltage gradient, electrode spacing, water resistance, angle of array in relation to stream flow, water velocit et cetera, on guiding effectivene are now being investigated in t Service's Seattle laboratory in effort to find the most favorab conditions for large-scale tests the field.

SUMMARY

The relation of pulse frequency and pulse duration to the effectiveness of a moving field of pulsating direct current in directing salmon fingerlings was explored under controlled laboratory conditions, utilizing a single-row electrical array.

In a range of pulse frequencies of 1 to 6 pulses per second and a range of pulse durations from 5 to 60 milliseconds, the most effective combinations found for divertir fingerlings are those with freque cies of 3 and 4 pulses per secon and duty cycles from 0.06 to 0.1 i. e., 3 pulses per second with pul durations of 20 to 30 millisecond and 4 pulses per second with pul durations of 15 to 25 millisecond

A slight loss in fish was observe in tests with duty cycles of 0.10 greater.

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APPENDIX

The tables in this appendix contain the data accumulated during the experiments in which the influence of pulse frequency and pulse duration on the guiding effectiveness of the single-row electrode array was studied. Throughout the experiments the following conditions were held constant:

1. Electrode spacing — 30 inches.
2. Angle of array — 25 degrees from direction of stream flow.
3. Voltage — 210 volts across each pair of electrodes.
4. Pulse wave form — "square" wave.
5. Electrode type — 2-inch-diameter tubular aluminum.
6. Water depth — 10 inches.
7. Water resistance — 14,000 to 16,000 ohms/cm.[3]
8. Water temperature — 12° to 14° C.
9. Water velocity — 0.5 feet per second.
10. Fish — silver salmon fingerlings (*O. kisutch*) 7 to 11 cm. in length.
11. Duration of each test — 5 minutes.
12. Light intensity — less than 1 foot-candle to 3.4 foot-candles.

Appendix table A.—Control salmon fingerlings recovered November 12 to 24, 1954

[Number released—1,110; percent recovered—92]

Date	Number of fish recovered	Recovered in narrow channel		Time of day	Number of deaths
		Number	Percent		
ov. 15	42	12	29	Morning	0
15	[1] 67	14	21	do	0
15	49	12	24	Afternoon	0
15	42	10	24	Evening	0
16	44	14	32	Morning	0
16	44	11	25	Afternoon	0
16	47	13	28	Evening	0
17	45	13	29	Morning	0
17	40	10	25.5	Afternoon	0
17	49	12	24.5	Evening	0
18	[1] 51	12	23.5	Morning	0
18	39	10	26	Afternoon	0
19	42	11	27	Morning	0
19	45	13	29	Afternoon	0
22	46	11	23	Morning	0
22	[1] 53	13	24	Afternoon	0
22	45	12	27	Evening	0
23	40	10	25	Morning	0
23	[1] 51	12	23	Afternoon	0
23	45	14	30	Evening	0
24	46	12	26	Morning	0
24	46	11	23	Afternoon	0
All dates	1,018	262	[2] 25.8		0

[1] Fish from previous tests remaining upstream above the experimental area moved down into the traps.
[2] Based on total fish recovered in the narrow channel.

Appendix table B.—Effect on salmon fingerlings of various pulse durations at a frequency of 1 pulse per second, November 1954

[Number released—1,200; percent recovered—78]

Pulse duration and date	Number of fish recovered	Recovered in narrow channel		Time of day	Number of deaths
		Number	Percent		
Duration of 20 milliseconds:					
Nov. 15	40	33	82.5	Morning	
23	43	30	70	do	
16	41	30	74	Afternoon	
23	41	27	66	do	
22	41	28	69	Evening	
26	38	25	65	do	
All dates	244	173	[1] 71		
Duration of 30 milliseconds:					
Nov. 15	38	27	71	Morning	
23	45	32	71	do	
16	38	26	70	Afternoon	
23	34	24	70	do	
22	36	25	69	Evening	
26	37	27	73	do	
All dates	228	161	[1] 70.5		
Duration of 40 milliseconds:					
Nov. 18	36	27	74	Morning	
23	34	25	73	do	
16	37	30	81	Afternoon	
23	40	27	68	do	
22	38	28	73	Evening	
26	42	31	74	do	
All dates	227	168	[1] 74		
Duration of 60 milliseconds:					
Nov. 18	41	31	76	Morning	
23	34	24	70	do	
18	37	24	65	Afternoon	
23	44	32	73	do	
22	37	27	72	Evening	
26	43	29	68	do	
All dates	236	167	[1] 70		
Grand total	935	669			

[1] Based on total fish recovered in the narrow channel.

Appendix table C.—Effect on salmon fingerlings of various pulse durations at a frequency of 2 pulses per second, November 1954

[Number released—1,500; percent recovered—75.5]

Pulse duration and date	Number of fish recovered	Recovered in narrow channel		Time of day	Number of deaths
		Number	Percent		
Duration of 10 milliseconds:					
Nov. 15	35	23	66	Morning	0
18	39	27	69	do	0
17	40	24	60	Afternoon	0
23	43	30	70	do	0
16	41	32	78	Evening	0
17	41	29	70	do	0
All dates	239	165	[1] 68.5		0
Duration of 20 milliseconds:					
Nov. 15	35	27	77	Morning	0
18	33	25	76	do	0
17	42	32	76	Afternoon	0
23	35	25	71	do	0
16	37	29	78.5	Evening	0
17	31	25	81	do	0
All dates	213	163	[1] 76.5		0
Duration of 30 milliseconds:					
Nov. 15	32	26	81	Morning	0
18	44	32	73	do	0
17	36	28	77	Afternoon	0
23	39	29	74	do	0
16	36	26	72	Evening	0
17	33	25	76	do	0
All dates	220	166	[1] 75.5		0
Duration of 40 milliseconds:					
Nov. 15	41	28	68	Morning	0
18	34	27	79	do	0
17	30	20	67	Afternoon	0
23	34	28	82	do	0
16	38	24	63	Evening	0
22	40	29	73	do	0
All dates	217	156	[1] 72.0		0
Duration of 60 milliseconds:					
Nov. 18	41	28	68	Morning	0
18	38	26	68	do	0
17	41	27	66	Afternoon	2
23	33	25	76	do	1
17	38	23	60	Evening	3
22	38	28	74	do	2
All dates	229	157	[1] 68.5		8
Grand total	1,118	807			8

[1] Based on total fish recovered in the narrow channel.

Appendix table D.—Effect on salmon fingerlings of various pulse durations at a frequency 3 pulses per second, November 1954

[Number released—1,800; percent recovered—82.5]

Pulse duration and date	Number of fish recovered	Recovered in narrow channel		Time of day	Num of dead
		Number	Percent		
Duration of 5 milliseconds:					
Nov. 16	54	41	76	Morning	
22	40	29	72	do	
17	47	31	65	Afternoon	
19	41	29	71	do	
15	42	31	73	Evening	
23	38	28	73	do	
All dates	262	189	[1] 72		
Duration of 10 milliseconds:					
Nov. 16	42	30	73	Morning	
22	41	31	76	do	
17	37	29	78	Afternoon	
22	37	30	81	do	
15	37	29	78	Evening	
23	37	26	70	do	
All dates	230	175	[1] 76		
Duration of 20 milliseconds:					
Nov. 16	35	27	77	Morning	
23	49	41	84	do	
17	34	27	79	Afternoon	
22	37	29	78	do	
15	38	31	82	Evening	
23	41	33	81	do	
All dates	234	188	[1] 80		
Duration of 30 milliseconds:					
Nov. 16	41	32	78	Morning	
23	42	30	71	do	
17	45	40	93	Afternoon	
22	46	39	85	do	
15	44	37	84	Evening	
23	45	36	80	do	
All dates	261	214	[1] 82.5		
Duration of 40 milliseconds:					
Nov. 18	36	28	77	Morning	
23	38	29	76	do	
17	50	44	88	Afternoon	
22	47	35	75	do	
17	38	31	81	Evening	
23	31	23	74	do	
All dates	240	190	[1] 79		
Duration of 60 milliseconds:					
Nov. 18	36	34	94	Morning	
23	44	36	82	do	
17	48	39	81	Afternoon	
22	37	24	64	do	
17	47	37	79	Evening	
23	44	37	84	do	
All dates	256	207	[1] 81		
Grand total	1,483	1,163			

[1] Based on total fish recovered in the narrow channel.

Appendix table E.—Effect on salmon fingerlings of various pulse durations at a frequency of 4 pulses per second, November 1954

[Number released—1,500; percent recovered—83]

Pulse duration and date	Number of fish recovered	Recovered in narrow channel		Time of day	Number of deaths
		Number	Percent		
uration of 5 milliseconds:					
Nov. 16	42	29	69	Morning	0
24	41	32	78	do	0
15	47	30	64	Afternoon	0
18	38	28	74	do	0
17	42	30	71	Evening	0
26	42	31	74	do	0
All dates	252	180	[1] 71.5		0
uration of 15 milliseconds:					
Nov. 19	43	34	78	Morning	0
24	35	29	83	do	0
15	32	25	81	Afternoon	0
18	40	33	82.5	do	0
17	44	40	91	Evening	0
26	46	36	78	do	0
All dates	240	197	[1] 82		0
uration of 25 milliseconds:					
Nov. 19	48	40	83	Morning	0
24	39	29	74	do	0
15	35	35	71	Afternoon	0
18	33	29	88	do	0
17	49	41	84	Evening	0
26	41	31	76	do	0
All dates	245	195	[1] 80		0
uration of 35 milliseconds:					
Nov. 19	43	32	74	Morning	0
24	47	33	70	do	1
15	37	27	78	Afternoon	0
18	43	34	79	do	0
17	39	31	79	Evening	0
26	45	33	73	do	0
All dates	254	192	[1] 75.6		1
uration of 45 milliseconds:					
Nov. 19	39	29	74	Morning	1
24	43	28	65	do	1
15	46	34	74	Afternoon	2
18	43	31	72	do	1
17	41	27	66	Evening	1
26	40	26	64	do	0
All dates	252	175	[1] 69.5		6
Grand total	1,243	939			7

[1] Based on total fish recovered in the narrow channel.

Appendix table F.—Effect on salmon fingerlings of various pulse durations at a frequency 5 pulses per second, November 1954

[Number released—1,500; percent recovered—79.3]

Pulse duration and date	Number of fish recovered	Recovered in narrow channel		Time of day	Numl of deatl
		Number	Percent		
Duration of 5 milliseconds:					
Nov. 17	35	30	86	Morning	
23	48	40	83	do	
15	49	34	70	Afternoon	
19	32	25	78	do	
16	37	26	70	Evening	
22	39	31	79	do	
All dates	240	186	[1] 77.5		
Duration of 10 milliseconds:					
Nov. 17	30	25	83	Morning	
24	40	30	75	do	
15	40	30	75	Afternoon	
19	39	30	77	do	
16	39	30	77	Evening	
22	42	36	86	do	
All dates	230	181	[1] 78.5		
Duration of 20 milliseconds:					
Nov. 17	34	29	85	Morning	
24	37	28	76	do	
15	34	36	84	Afternoon	
19	39	32	82	do	
16	40	34	85	Evening	
22	38	29	77	do	
All dates	232	188	[1] 80.5		
Duration of 30 milliseconds:					
Nov. 17	43	38	89	Morning	
24	38	27	71	do	
15	38	31	82	Afternoon	
19	39	32	83	do	
16	38	33	87	Evening	
22	35	28	80	do	
All dates	231	189	[1] 81.5		
Duration of 40 milliseconds:					
Nov. 17	41	32	78	Morning	
24	44	28	63	do	
15	41	25	61	Afternoon	
19	45	29	64	do	
16	42	24	57	Evening	
22	44	30	68	do	
All dates	257	168	[1] 65.5		
Grand total	1,190	911			

[1] Based on total fish recovered in the narrow channel.

ppendix table G.—Effect on salmon fingerlings of various pulse durations at a frequency of 6 pulses per second, November 1954

[Number released—900; percent recovered—79]

Pulse duration and date	Number of fish recovered	Recovered in narrow channel		Time of day	Number of deaths
		Number	Percent		
ration of 5 milliseconds:					
Nov. 15	44	28	64	Morning	0
22	32	22	69	do	0
16	38	24	63	Afternoon	0
24	36	25	70	do	0
15	47	30	64	Evening	0
23	45	30	67	do	0
All dates	242	159	[1] 65.5		0
ration of 10 milliseconds:					
Nov. 15	30	21	70	Morning	0
22	35	26	74	do	0
16	39	28	72	Afternoon	0
24	50	35	70	do	0
15	42	29	70	Evening	0
23	40	31	77	do	0
All dates	236	170	[1] 72		0
ration of 20 milliseconds:					
Nov. 17	44	33	75	Morning	2
22	30	23	65	do	3
16	35	23	66	Afternoon	1
24	39	30	77	do	1
15	41	31	76	Evening	1
23	45	31	69	do	2
All dates	234	171	[1] 73		10
Grand total	712	500			10

[1] Based on total fish recovered in the narrow channel.

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